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THE INFLUENCE OF THE TOOL POINT ANGLE AND FEED RATE ON THE DYNAMIC PARAMETERS AT DRILLING COATED PARTICLEBOARD

Mihai ISPAS
Prof.dr.eng. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: ispas.m@unitbv.ro

Sergiu RĂCĂŞAN
Assist.dr.eng. – TRANSILVANIA University in Brasov – Faculty of Wood Engineering
Address: B-dul Eroilor nr. 29, 50036 Brasov, Romania
E-mail: sergiu.racasan@unitbv.ro

Abstract:
Pre-laminated (coated) particleboards (PB) are wood-based composites intensively used in the furniture industry. In order to prepare the PB for joining, drilling is the most commonly applied machining process. The surface quality and the dynamic parameters (thrust force and torque) are significantly influenced by the tools characteristics and the machining parameters. The point/tip angle of the drill bit and the feed speed during drilling play a major role in gaining a good surface quality and minimizing the dynamic parameters. The objective of this study was to measure and analyze the influence of both the geometric and cinematic parameters on the dynamic parameters at drilling with twist (helical) drills. The experiments were performed based on a factorial design. The results show that, a low feed rate generally minimizes both the drilling torque and the thrust force, while a small tip angle increases the drilling torque and minimizes the thrust force.

Key words: *drilling, particleboard, tool geometry, thrust force, torque.*

INTRODUCTION

Drilling is one of the most common and frequent mechanical processing operations not only in the wood industry, but also in the processing of metals, plastic materials, composites etc. In the furniture industry it has been more and more employed over the years, along with the massive development of body furniture production, obtained from panels joined by cylindrical tenons.

Therefore, although the economical importance of the drilling operation has been constantly growing and will continue to grow, gaps in knowledge are still registered, especially regarding the relationships between the geometrical parameters of the drill bits, the cinematic parameters of the working schedule (cutting speed and feed speed), and the dynamic parameters (thrust force and torque), which in turn influence both the quality of drilling and the energy consumption.

Research on wood drilling is not new. Ozenberg (1927) has investigated the chip evacuation mode, the influence of the drill bit diameter and of the cutting edge geometry on the torque and feed speed (the thrust force being maintained constant) for different types of drill bits and for several wood species (beech, poplar, alder, birch, spruce).

The researches conducted by Hetzel (1928) focused on the PB and plywood drilling. Investigations aimed at determining the influence of the adhesive on the cutting edge durability, the influence of the drill bit type and diameter, and the cutting edge geometry on the torque and feed speed (the thrust force being maintained constant), as well as on the chip formation relative to the torque and feed speed.

Buttner (1929) investigated the influence of the helix angle and point/tip angle on the thrust force and torque for several helical drills and wood species. Serebrianîi (1954) studied the drilling dynamic parameters (thrust force and torque), as well as the chip formation and evacuation mode relative to the drill type and diameter, the wood species, the feed speed, the drilling depth and the geometry of the tool active part.

Radu (1967) achieved an extensive study aiming at establishing the optimum drill characteristics for wood and PB drills, considering the torque, the thrust forces and the chip evacuation mode as function of the drill type, the wood species (oak, beech, spruce, PB), the feed speed and the drilling depth. The results showed that, as long as the point/tip angle increases, the torque and the specific resistance to cutting decreases, but the thrust force increases too, regardless the feed direction.

The author also noticed that the processing quality (expressed through fibre plucking and tearing at the inlet and outlet orifices) decreases when the thrust force and point/tip angle increase. In the same study, Radu (1967) also investigated the influence of the helix angle on the torque and thrust force. For the studied situations, minimal torques and thrust forces were recorded at helix angle values of between 35° and 41°. The drilling quality was found best for a helix angle of 38°.

Based on previous studies performed by Zhao (2000), Zhao and Ehmann (2002) developed an optimised geometry for a new class of spade drill bits for wood processing. The authors studied both theoretically and experimentally the influence of the proposed geometry on the performances of the new tools. The results showed that both the thrust force and torque decrease with the increase of the drilling rotation speed, and with increasing feed speed (feed rate).

Valarmathi et al. (2012) found that the high spindle speed with low feed rate reduces the thrust force developed by the drilling of plain MDF panels. Also, based on the idea that the thrust force developed during drilling of PB plays a major role in gaining a good surface quality and minimizing the delamination tendency, Valarmathi et al. (2013) studied the influence of the spindle speed, feed rate and point angle on the thrust force.

Studies on the processing PB with flat drills by Ispas et al. (2014) have showed that a low feed rate generally minimizes both the drilling torque and the thrust force, while a small tip angle generally increases the drilling torque and minimizes the thrust force.

In conclusion, research on drilling prelaminated PB are few, and those that exist are made with drill bits with geometry features more characteristic for metal processing (tip angle $2\kappa_r \geq 100°$, feed speeds v_f = 75 - 225 mm/min). The present study envisages the influence of the tool geometry (tip angle) and processing parameters (feed speed) on the dynamical parameters (thrust force and torque) at pre-laminated PB drilling, in typical woodworking conditions.

OBJECTIVES

The objective of this study was to evaluate the influence of the tool geometry and feed rate on the dynamic parameters (thrust force and torque) developed during the drilling of coated PB.

METHOD AND MATERIALS

The experiments were performed using 4 twist (helical) drill bits with 10mm cutting diameter, with different tip angles ($2\kappa_r$ = 30°, 60°, 90°, 120°) and one lip and spur drill bit (Fig. 1). The clearance angle of all drills was the same α = 20°. The symbols used for these drills were tip angle related; T30, T60, T90, T120, respectively TLS for the lip and spur drill.

Fourty square samples ☐80mm were cut from a single pre-laminated 18mm thick particleboard (Fig. 2a). They were divided into four groups of ten specimens each. Each specimen was drilled with five different drills (T30, T60, T90, T120, respectively TLS) (Fig. 2b).

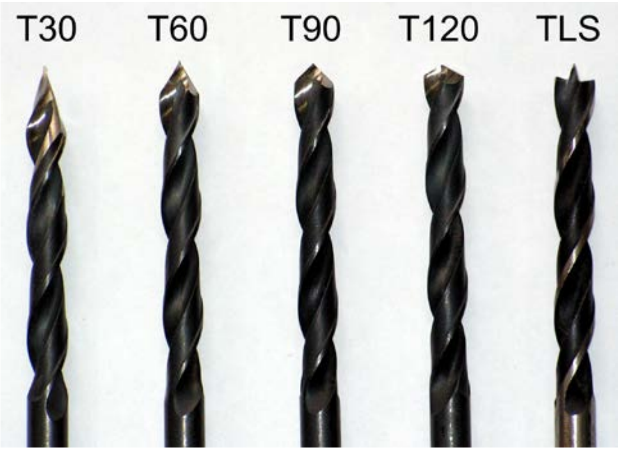

Fig.1.
The drill bits used for processing

Each group of ten specimens was drilled with a different feed speed so that the tooth bite, f_z, was different, having the following values: 0.1, 0.3, 0.5 and 0.7mm. The rotation speed of the drills was the same, n = 3000rpm. This led to four feed speed values, v_f = 0.6, 1.8, 3.0 and 4.2m/min.

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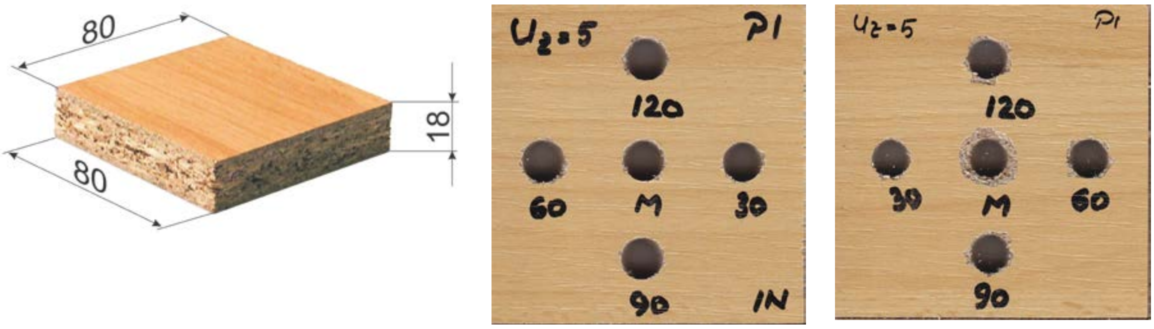
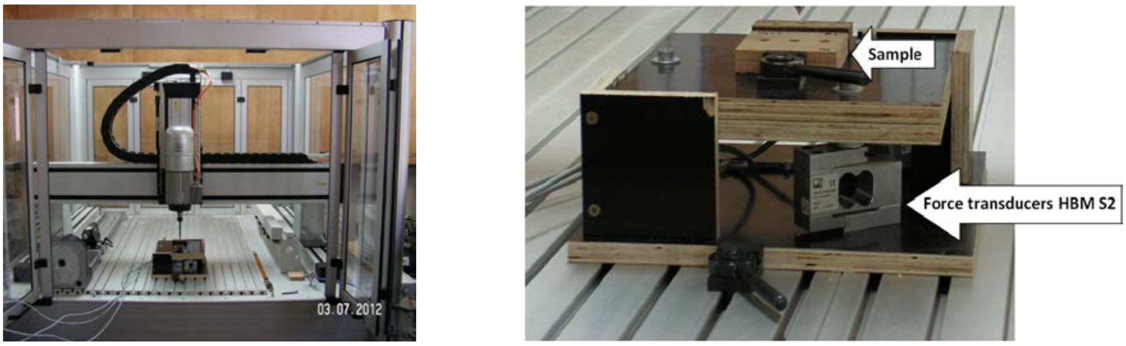


a. b.

Fig. 2.
The samples used for processing: PB sample (a) and drilled sample (b)

The processing machine was a CNC processing centre type ISEL GFV/GFY, which allowed the exact set-up of the drills rotation speed and of the feed speeds (Fig. 3a).

The device used to measure the thrust force (Fig. 3b) consists of three HBM force transducers type S2 (nominal force: 500N), placed at 120 °, at the same distance from the drilling axis.

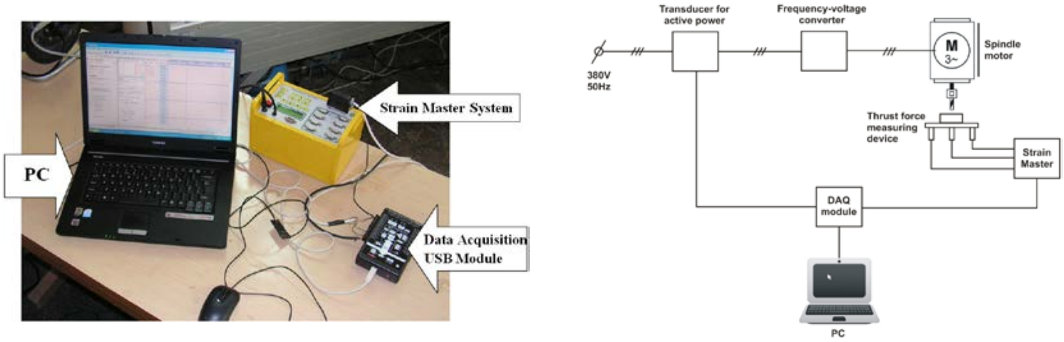


a. b.

Fig. 3.
Machine tool and measuring device:
a - CNC processing centre type ISEL GFV/GFY; b - Device built for measuring the developed forces

In order to amplify the signal from the force transducers to the data acquisition board, a Strain Masters signal amplifier was used. This electronic device is designed for static and dynamic strain measurements using quarter, half, and full bridge circuits, with 8 independent channels.

The torque was evaluated by measuring the active power consumed by the spindle motor. This was measured by a Sineax P530/Q531 transducer for active and reactive power (Camille Bauer). The data were recorded with a multifunction DAQ Board Keithley Model KUSB-3108. The apparatus was connected into the electric circuit of the machine motor, according to the scheme presented in Fig. 4.



a. b.

Fig. 4.
DAQ system used for measurements (a) and the connection scheme (b)

The data were stored on a PC using the Keithley KUSB QuickDataAcq software (Fig. 5). The first channel represents the values of the active power P_T consumed by the spindle motor during drilling. This includes both the power consumed at idle running P_0 and the one consumed during drilling P_D. The following three channels represent the force values recorded in feed direction by each force transducer, their sum representing the thrust force F_T. For each drilling operation a data file was obtained, so a total of 200 files (4 feed speeds x 5 drill bits x 10 samples = 200 drilling operations).

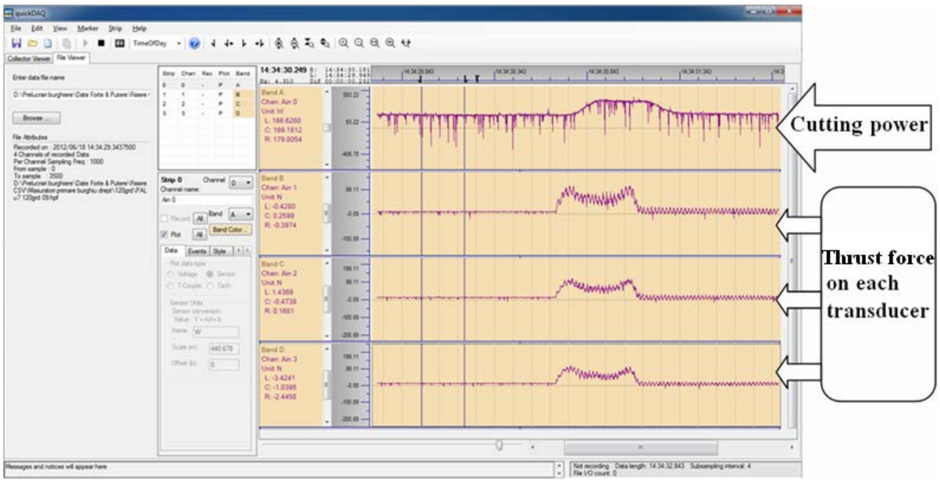


Fig. 5.
Window of the DAQ software Keithley KUSB QuickDataAcq

Data processing

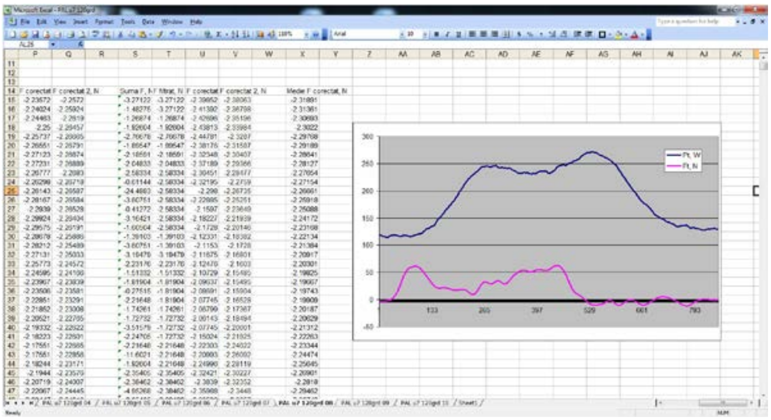
The data processing was performed by means of the MICROSOFT EXCEL 2003 programme under WINDOWS 7. For this, the acquired data were exported in .xls format. In order to remove the noise and the dynamic components of the signals, these were filtered by a fourth-order, Butterworth digital filter.

After filtering, the data from the channels 2, 3 and 4 were summed 3 by 3 to get the variation of the thrust force (Fig. 6a). Next, the average values of consumed active power and thrust force for each pair drill - feed speed were calculated (Fig. 6b) (as previously shown with each pair drill - feed rate there have been performed 10 drillings on 10 different specimens).

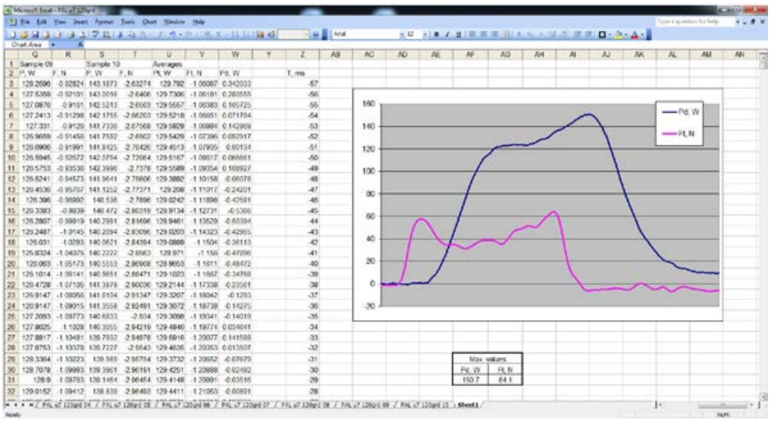
Finally, the data representing the consumed active power P_T were processed in order to obtain the variations of the drilling torque T_D, according to the well-known formula:

$$T_D = 9.55 \frac{P_D}{n} [N \cdot m] \tag{1}$$

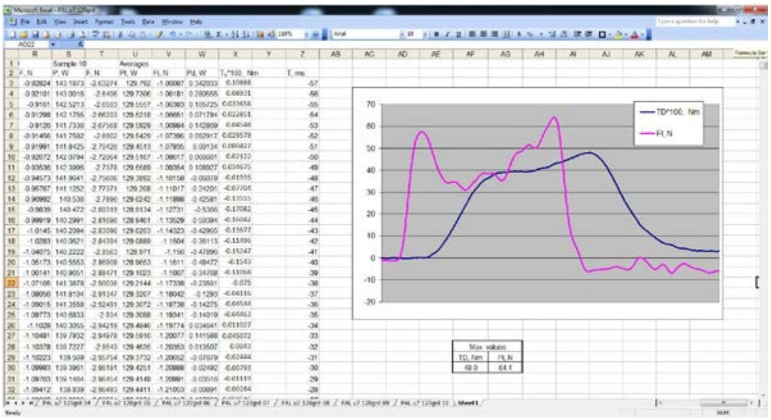
where: P_D is the power consumed only for drilling, $P_D = P_T - P_0$, in W;
n – spindle rotation, in rpm.



a.



b.



c.

Fig. 6.

Variation of the consumed active power P_T, the drilling power P_D, the thrust force F_T and the drilling torque T_D (drilling with T120 at f_z=0.7mm):
a- P_T (W) and F_T (N) for one drilling operation (instantaneous values, after filtering),
b- P_D (W) and F_T (N) averages for ten drilling operations,
c- T_D*100 (Nm) and F_T (N) averages for ten drilling operations

Diagrams similar to those in Fig. 6 have been made for all the processing situations (all tools and all feed speeds).

For each drill, three distinct phases of processing can be observed (see Fig. 6):

- phase 1, the stage when the drill starts cutting and the entire cutting tip penetrates into the material (the initial penetration); in this phase both the thrust force and the drilling torque increase sharply;
- phase 2, when the drill cuts into the material, until the drill tip crosses the whole board thickness (the actual drilling); in this phase both the thrust force and the drilling torque remained broadly unchanged (relative small variation);
- phase 3, when the cutting tip begins to emerge from the material and achieves the complete breakthrough; in this phase both the thrust force and the drilling torque decrease rapidly.

RESULTS AND DISCUSSION

The final results of the measurements on the evolution of the drilling torque and thrust force showed that for each drilling operation, the variation of forces and moments according to the three phases of processing can be observed. It can be seen that, in the first phase, they grow until the cutting edges cut with their entire length, in the second phase they slightly decrease due to the core area of PB (drills T60, T90, T120) and in the exit phase of the cutting edges they finally decrease, along with the power consumption as well.

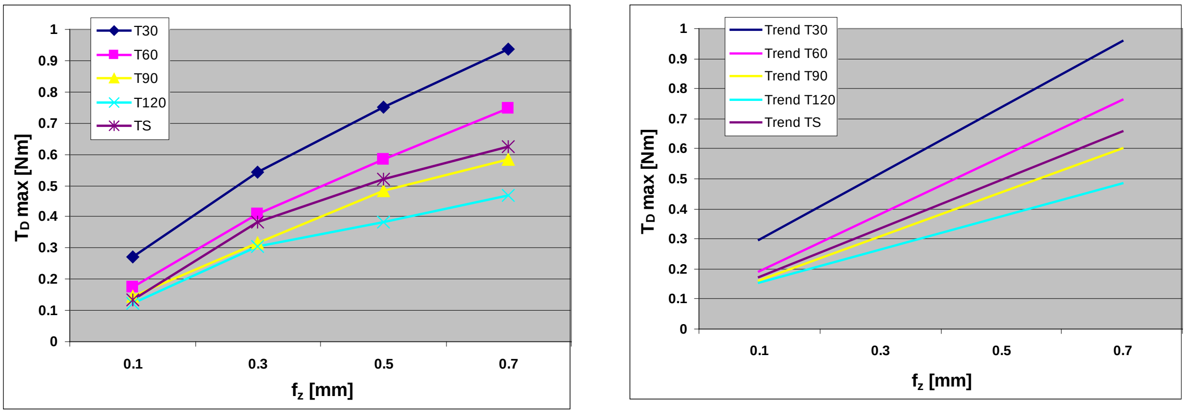
It can be noticed that the highest values for the drilling torque are recorded for processing with the drill bit T30, but only for a very short period, while the cutting edges cut through the entire thickness of the specimen (the T30 drill tip length is 18.66mm while the samples thickness is only

18mm). The lowest values of the drilling torque were recorded with the drill bit T120. These results are fully consistent with the length of the cutting edges.

The lowest values of the thrust force were recorded with the drill bit T30 and the highest values with the TLS drill bit. These results are fully consistent with the tools point angles.

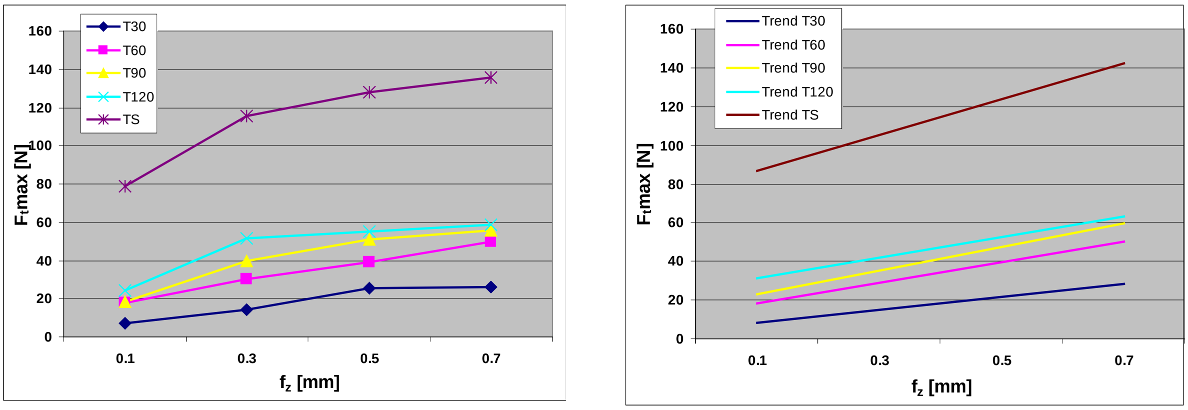
Both the drilling torque and the thrust force increases with increasing feed per tooth.

The graphical representation of the maximum values of torque and thrust force, respectively of their trendlines are presented in Fig. 7 and 8.



a. ***b.***

Fig. 7.
Maximum values of torque: averages (a) and trendlines (b)



a. ***b.***

Fig. 8.
Maximum values of thrust force: averages (a) and trendlines (b)

The graphs show a small desynchronization of the power consumption compared to the thrust force. This slight delay is most likely due to the flywheel effect of the spindle.

An interesting thing to be mentioned is that both the thrust force and the drilling torque recorded when drilling with helical drills were much lower than those recorded when drilling with flat drills, under similar conditions: same processed material, same hole diameter, same rotation speed, same feed speeds, same point angles (Ispas et al, 2014). Thus, the torque was generally less than 50% and the thrust force was 4 times lower when processing with the tools T30, T60, T90 and T120, and with approximately 20% lower when drilling with TLS.

CONCLUSIONS

The objective of this study was to evaluate the influence of the tool geometry (the tip angle) and feed rate (feed per tooth, f_z) on the dynamic parameters (thrust force and torque) developed during the drilling of coated PB. The results show that with the increase of the tip angle, the drilling torque decreases. For the thrust force the situation is opposite. Thus, with the increase of the tip angle the thrust force increase.

This study confirms the results of other studies conducted in other or similar conditions (materials and tools) namely the fact that, at the PB drilling, with the increase of the feed rate, the values of dynamic parameters (torque and thrust force) also increase.

This study has not exhausted the multitude of situations encountered in practice. Other possible directions of research on this issue are: processing with other drilling rotation speeds (lower or higher than 3000rpm), other drill bits types, the study of the drilling process from the point of view of the processing quality.

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